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ANNEX "A"

ESTIMATE OF BLAST AND THERMAL EFFECTS ON MIKE SHOT - OPERATION IVY

by

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CHAPTER I

GENERAL

The large size of the Mike weapon, together with a considerable uncertainty in predicted yield, present unusual problems in estimating blast and thermal effects.

Because of the limited size of Eniwetok Atoll, one cannot afford the luxury of protecting island installations against any possible yield, and for that matter, it would be imprudent to attempt to do so. Fortunately, the blast and thermal effects scale in such a way that no prohibitive problems are introduced, but every reasonable precaution must be taken and ingenuity used to reduce the calculated risk to a minimum.

The Test Director has formulated the policy that personnel protection will be based on an absolute upper estimate of yield. Structures or things will be protected on the basis of a reasonably probable yield. The wisdom of this policy is especially evident in blast, where the structural criterion for damage is seldom known better than a factor of 2; for the marginal case at low pressures, experience indicates that the effort required to protect structures is usually much greater than the effort required to repair whatever minor damage might occur.

The most likely value of yield for Mike shot is of the order 5 to 10 MT, and there is a very small probability that the yield may go as high as 50 MT. Both blast and thermal effects are such that the yield of 5 to 10 MT is reasonably safe. It is understood that should the probable yield later appear to be in the order of 50 MT, Los Alamos Scientific Laboratory will so inform all test personnel and the general conclusions of this paper should be reviewed at that time.

CHAPTER 2

BLAST EFFECTS

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2.1 General

Certain factors lend simplicity to the estimate of blast effects on the Mike shot. Because it is a surface burst, a reflection factor of 2 has been assumed for these predictions, meaning that the blast wave is a hemisphere whose peak pressures and waveforms and radii are appropriate to a bomb of twice the yield in free air. Because of the large scaled size of the explosion, compared with the shot island, the burst is essentially over water, which is an excellent

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reflecting surface in all respects. During the early strong shock phase, the rate of work by the shock front on air as compared to its rate on soil or water is in a ratio more than 100 to 1 in favor of air. It follows that less than 1 per cent of the energy will be transmitted to soil or water during these stages. Recent atomic tests have been concerned with the effect of thermal radiation in attenuating the peak pressures in a blast wave; this effect will be at a minimum on Mike shot because of the glancing angles of incidence of thermal radiation; however, the "Thermal effect" will not be completely absent because the fireball attains a large vertical height in a short time.

Other factors lead to difficulty in estimating the effects. The rise of the fireball and consequent afterwind lead to an attenuation of the blast wave at close distances which is difficult to estimate; this effect is at a maximum because of the low height of burst. Next, considerably higher temperatures may be achieved in this explosion than on an ordinary nuclear explosion; this leads to greater losses in energy through irreversible heating, to a different "partition of energy", to the possibility of a greater fraction of energy appearing as thermal radiation, and to the possibility of a smaller comparable blast yield. Again, the explosion is so large that the atmosphere can no longer be considered as homogeneous; the top of the blast wave will be in rarefied atmosphere at a time when ground pressures are still in the region of practical interest. Considerable blast experimentation will be devoted to this point which may lead to a variation of 25 per cent in yield. Again, atmospheric inversion may focus energy upward or downward at long distances, but for an ordinary bomb, this effect is usually at pressures near 0.1 psi. On Mike shot, the scaled height of these inversion layers are such that some focussing (or defocussing) of energy may occur at pressures of interest. Finally, on the space scale involved here, layers of clouds are close enough to be of some concern both from the standpoint of energy reflection as well as from the standpoint of providing a shield from thermal radiation.

For the most part the uncertainties listed are expected to be in the order of 25 to 50 per cent in blast yield, and small compared to the design uncertainty of 5 to 50 MT, and not sufficiently large to require specific numerical treatment.

For the most part, the data used in making these estimates were taken from IBM problem M, which was assumed to be 10 KT. This is nonconservative because it implies that blast efficiency of an atomic bomb is 0.65 compared with TNT. The actual efficiency may be as low as 0.5 for a conventional weapon and perhaps lower for a very large weapon. Moreover, experience on structures are usually based on pressure gauge readings, and these are generally lower, perhaps 20 per cent, than the "ideal" values quoted here.

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2.2 Derived Curves

2.2.1 Peak Overpressure vs Distance

Figure 1 shows the peak reflected overpressure as a function of distance for the yields indicated. Although these values have been taken from the IBM solution (in order to be consistent with other curves which follow) these predictions are in good agreement with predictions made on the basis of Greenhouse tower shots. There is a substantial difference; the tower explosions were on a scale small enough that the pressures recorded were essentially over a land surface. In this case, the explosion occurs over water, the present theory indicates that somewhat higher peak pressures should be observed than if the explosion occured entirely over land. Within the first few miles from the bomb, the peak pressures may be reduced considerably from the value shown here by the thermal effect on the ground prior to shock arrival. At long distances, such as at Parry and Eniwetok, the pressures may be lower or higher for reasons cited in Sec. 2.1 above. However, at long distances, the peak pressure is a slowly varying function of yield, such that an eight-fold increase in yield merely doubles the pressure.

2.2.2 Peak Material Velocity vs Distance

Coincident with the arrival of the shock wave is a wave of material velocity whose peak value as a function of distance is given in Fig. 2. The relationship between peak material velocity and peak pressure is

$$u = \frac{5\,\frac{\Delta P}{P_o}}{\sqrt{7(6\frac{\Delta P}{P_o} + 7)}} \cdot C_o$$

where

u = material velocity

C_o = ambient sound velocity

$\Delta P/P_o$ = overpressure, in atmospheres

The duration of this wind is comparable to the positive duration of the blast pressure.

2.2.3 Pressure vs Time

Figures 3, 4, 5, and 6 give estimates for the pressure vs time wave at selected pressure levels of 1,000, 100, 10 and 1 psi and indicate the variation in the form of the pressure wave at these pressure levels. At high pressures and close in there is no negative phase; pressure decays assymptotically to zero. Moreover, "length of the positive phase" is strongly influenced in this region by the rise of the fireball, which attenuates pressures shortly after shock arrival, and should reduce the

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"length of the positive phase." Within the first few miles the thermal effect will lead to a marked attenuation of peak pressures and the usual slow rise in pressure, instead of the ideal curve shown here. At slightly greater distances, the termal effect will result in a "partial shock" rather than a completely slow rise. Still further, the shock front will be sharp as shown here. At far distances the negative phase increases and eventually the positive and negative impulse under the blast wave become equal.

In translating these curves to different yields, both the distance and time must be scaled by $W^{1/3}$, holding pressures constant. In many cases, the criterion for structural damage is not simply peak pressure, but the product of the air density and the square of the material velocity $\frac{1}{2}\rho u^2$, this blast wind results in a dynamic pressure on structures; the time variation of this dynamic pressure may be taken as approximately similar to the pressure-time curves shown here.

2.2.4 Time of Arrival

Figure 1 gives the time of arrival of the shock wave as a function of distance. These curves are based on calculations from peak pressures observed on tower shots, but are in good agreement with the time-of-arrival curve as predicted from the IBM run using this yield. Unlike peak pressures, the observed time of arrival should be independent of the type of surface.

2.2.5 Positive Duration

Figure 8 shows the duration of the positive phase of the blast wave as a function of distance from the bomb. The upward swing of this curve at short distances is associated with the lack of a negative phase at this point. Where accurate estimates of the pressure decay is required at close-in distances, the pressure-time curves may be fitted by a power law or semi-logarithmic plot. For example, the curve shown for 1,000 psi can be fitted initially by

$P \sim 1/t^{.68}$ and later by $P \sim 1/t^{.8}$ or $P \sim P_s e^{-KT}$.

2.2.6 Positive Impulse vs Distance

Figure 9 shows the positive impulse, or $\int p\,dt$ as a function of distance. If further information is desired, such as the negative impulse, these values can be derived upon request.

2.3 Protection from Blast

2.3.1 General Rules

As pointed out earlier, every reasonable precaution must be taken against the blast effects and every method which ingenuity suggest should be used, but no prohibitive problems are presented by blast. It is impossible to point out here the criterion for all types of structures, but the following discussion shows the general character of the conclusions which may be expected. It is suggested that test personnel consider their individual structures on the basis of the field variables given in Figs. 1 thru 10.

2.3.2 Previous Experience

Some estimates for the damage on structures at different pressure levels are given in "Effects of Atomic Weapons"; a more complete table is available in Par. 48 and Table 9 of "Capabilities of Atomic Weapons", Department of the Army, Tech Manual TM-23-200, Department of the Navy, OPNAV-P-36-00100, Department of the Air Force, AFOAT 385.2, July 1951.

It should be noted that structures fail from two causes; from peak pressure and from the winds following the blast wave. From the standpoint of pressures, the Mike shot presents no pressures much beyond present experience. According to Fig. 1, pressures on Parry and Eniwetok will be about 0.75 psi; pressures [redacted] were observed on Parry and Eniwetok from Dog and George shots during Operation Greenhouse. A pressure [redacted] was observed on Bijiri from Dog shot. In both cases, numerous structures were involved, which should furnish pertinent data. The reason for this small increase in peak pressure is because the increase in yield ($P \sim W^{1/3}$) is offset by the greater distance. (Elugelab is approximately 22 miles from Parry, compared with 9 miles on Runit.) With respect to wind loading, the situation is more serious because the positive durations scale like $W^{1/3}$, and are not offset by an increase in distance. The positive durations for 5 MT are 10 times longer than for 5 KT at the same distance.

2.3.3 Structures

Some general conclusions may be drawn with regard to structures. All ordinary window or plates glasses, especially in sizes over 12 in. are nearly bound to break, on Parry and Eniwetok. Where possible, walls facing the blast wave should be removed as well as walls directly behind it, in order to allow pressures to build up more rapidly within the structure, and to relieve the force from normal reflection of the blast. If this is not feasible all windows and doors should be left open. No canvas can be used unless it is strongly secured with at least grommet-type fastening; plenty of slack should be allowed, without taut surfaces; no large unsupported separations of canvas should be draped over frame work. All tents should be struck, (although tents were observed to survive at Nevada Test Site at approximately this pressure level, but much shorter duration). The use of berms or sandbagging to protect structures is of doubtful value; the waveform is so long that the peak pressure can build up behind the berm before any appreciable decay has occurred; of course, some protection is afforded from the dynamic wind.

Small plywood structures have been observed to withstand 2 psi during some previous tests and although they failed at slightly higher pressures, they did so through multiple reflections from corners. Door frames and hinges fail readily if exposed to the blast much above 1 psi. Holmes and Narver reports no damage on the hanger at Eniwetok from 0.3 psi on previous shots. At the 0.8 psi level they report that structures bowed on a large wall facing the blast.

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It is noted that structures do not fail at some critical pressure level, but that over a range of pressures (perhaps a factor of 3), the damage is somewhat proportional to the pressure. The observation on structures at low pressure levels can be extrapolated with some degree of confidence without expecting a sudden and complete collapse. In most cases, there is always some weak element on a structure which will fail first; such as blowing in of a panel; in stress.

2.3.4 Vehicles

There is of no apparent requirement to evacuate vehicles from Parry to Eniwetok nor any appreciable advantage in doing so. All canvas tops should be removed from the vehicles. Windshields should be lowered flat or removed entirely. The vehicle should face directly away or toward the blast although it is felt that better protection for the radiator and headlights is afforded if the vehicle is facing away from the blast.

2.3.5 Aircraft

All aircraft should be evacuated wherever possible. For small aircraft (including helicopters) which cannot be evacuated, the main wings should be removed, and if left in the open, the aircraft should face toward the blast.

2.3.6 Boats

No damage is expected to hulls or any part of water craft which is usually subjected to wave action. The .7 psi level is equivalent to a head of a 1/2 foot of water which such boats habitually withstand. The superstructures of these craft are more susceptible to blast damage but we recall that the unbalanced peak pressure is of very short duration, small objects being rapidly engulfed by the pressure wave; for example, a mast of 3 in. in diameter will feel the peak pressure for approximately 1/4 of a millisecond. Following the peak pressure the blast winds will be of the order of 40 to 50 miles per hour at Parry or Eniwetok but these craft habitually withstand these winds.

2.3.7 Storage Tanks

Storage tanks for fluids should be left full, both to add mass as well as to prevent the plates from buckling in.

CHAPTER 3

THERMAL EFFECTS

3.1 General

Like blast, an estimate of thermal effects required answers to certain uncertainties which will be settled by some of the experiments on the Operation itself. Fortunately, again, the estimates for thermal radiation are sufficiently low that no prohibitive problems are introduced.

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There is an uncertainty in scaling radiation which involves whether the thermal yield is proportional to radiochemical yield or proportional to some lower power such as $W^{.73}$. In this paper, the theoretical upper limit is assumed and this in itself may give values 2 to 7 times higher than actually obtained. There is also an uncertainty regarding the transmission of air, because the fireball rises rapidly to great heights. Near the surface of the water, transmission is quite low, but several hundred feet above the water the transmission increases markedly. The transmission assumed here is for very clear air and considered reasonably safe. Although Elugelab is several hundred feet below the horizon at Eniwetok, no protection is afforded from thermal radiation because the fireball rapidly grows to a diameter many times this value.

A distinctive feature of the thermal radiation on this explosion will be the long time scales involved, nearly 10 times that from a 5 KT bomb. It may be possible to see the light minimum and the subsequent increase to maximum radiation, around 2 seconds. The thermal radiation will persist for some 30 seconds instead of the 3 seconds for conventional size weapons. Personnel should be warned that it is necessary to keep on the dark goggles for much longer periods of time than for conventional size weapons.

3.2 Total Thermal Radiation vs Distance

Figure 10 shows the total thermal radiation in calories/cm^2 as a function of distance from the bomb. These curves have been derived using the assumption that the total thermal radiation will represent 1/3 of the total yield. The dotted lines represent the values of total thermal radiation which would be received if one completely neglected absorption of thermal radiation by air. The full lines are based on a transmission of 80 per cent per mile, and corresponds to a very clear atmosphere. The full lines are considered reasonable estimates for structures near the ground. The dotted lines are an exaggerated upper limit, more appropriate to high flying aircraft.

3.3 Temperatures of Surfaces Exposed to Thermal Radiation

Both the "Effect of Atomic Weapons" and "Capabilities of Atomic Weapons" contain tables which give the critical energies in calories/cm^2 for a number of common materials such as wood, cloth, rubber, and plastics. The long duration of thermal radiation of this weapon has the effect of increasing these critical energies by a factor of 3 above the critical energy required on a conventional size weapon. The total thermal radiation occurs over longer periods of time, this permits correspondingly longer periods for heat to be conducted away from the surface and into the interior of their radiated object. For substances which are not shown in such tables the average surface temperature may be estimated roughly from the following equation:

$$T_s = \frac{aQ_T}{\sqrt{1.76}} \sqrt{\frac{1}{k\rho\sigma}} \cos\theta$$

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Where

a = absorptivity of the surface

T_s = surface temperature, degrees centigrade

W = radiochemical yield, kilotons

h = specific heat, cal/gm deg

ρ = density, gm/cm^3

σ = thermal conductivity, cal/cm, deg, sec

θ = angle of incidence of thermal radiation of the surface.

Based on this equation and a yield in the order of 5 MT, Table 1 shows the relationship between the surface temperature and the total thermal radiation, for surface directly exposed to the radiation, where T_s is the rise in surface temperature in °C, and Q_T IS THE TOTAL incident thermal radiation in cal/cm^2, as given in figure 10.

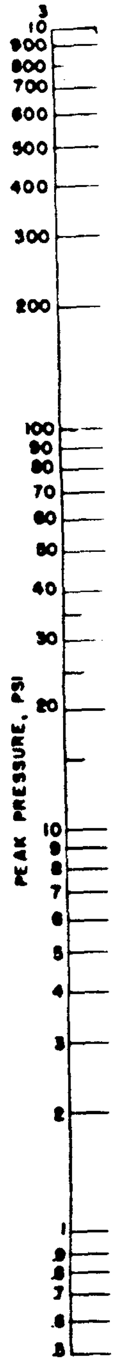
TABLE 1

Copper	$T_s = 0.1\ Q_T$
Aluminum	0.1
Steel	0.4
Cement	5
Asbestos	10
Rubber	18
Wood	18

[redacted]

The equation above is not strictly correct because it assumes that the thermal radiation rate is proportional to $1/t^2$. This is reasonable approximation after 2 seconds but prior to this time, the radiation rate varies in such a way that the surface temperatures may momentarily go to a value perhaps 3 times those estimated from the above equation.

Table 1 shows that the most critical materials are rubber and wood. For 5 MT yield, however, the temperature rise will be neglible for such materials on Parry and Eniwetok.



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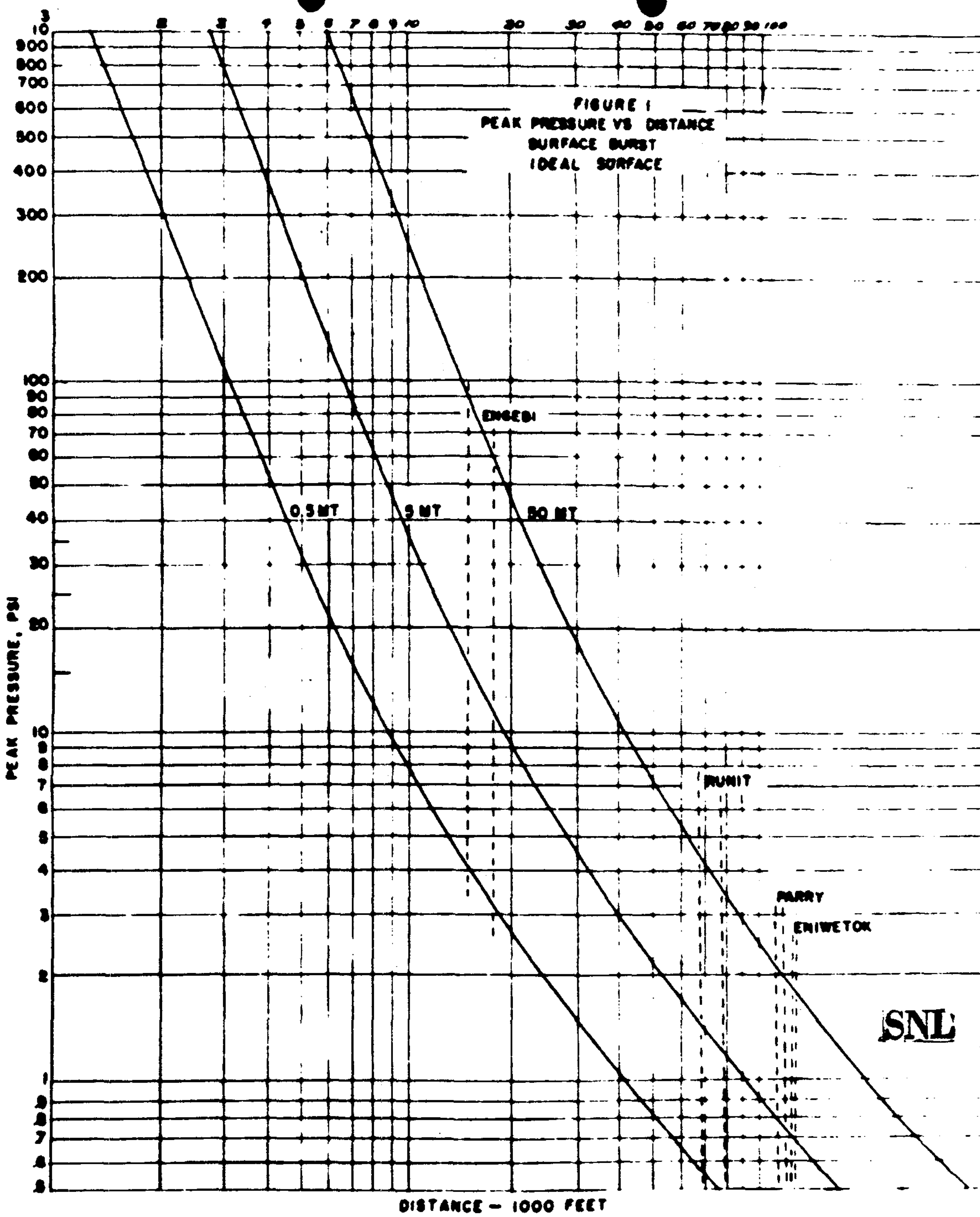

FIGURE 1
PEAK PRESSURE VS DISTANCE
SURFACE BURST
IDEAL SURFACE

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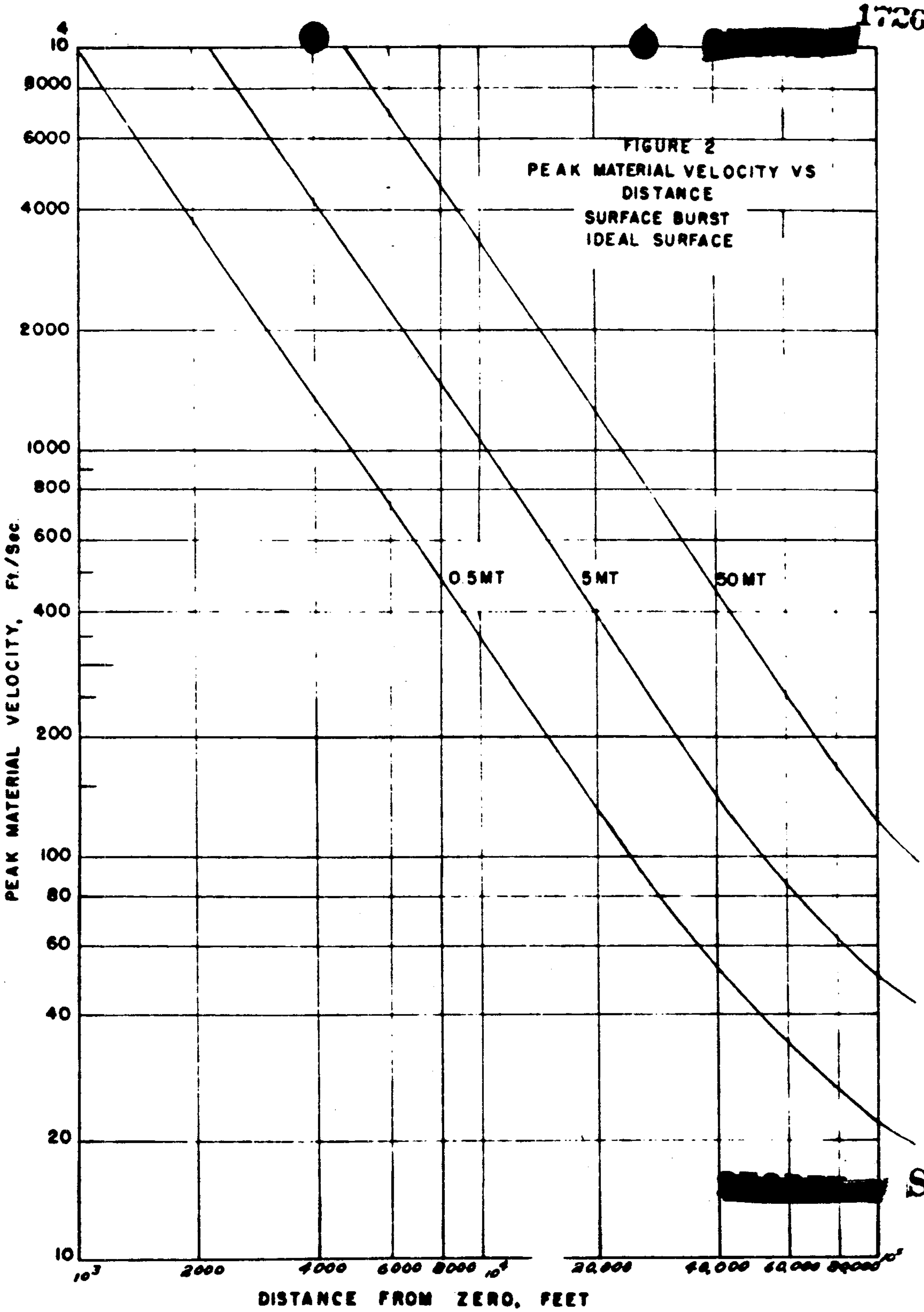

FIGURE 2
PEAK MATERIAL VELOCITY VS DISTANCE
SURFACE BURST
IDEAL SURFACE

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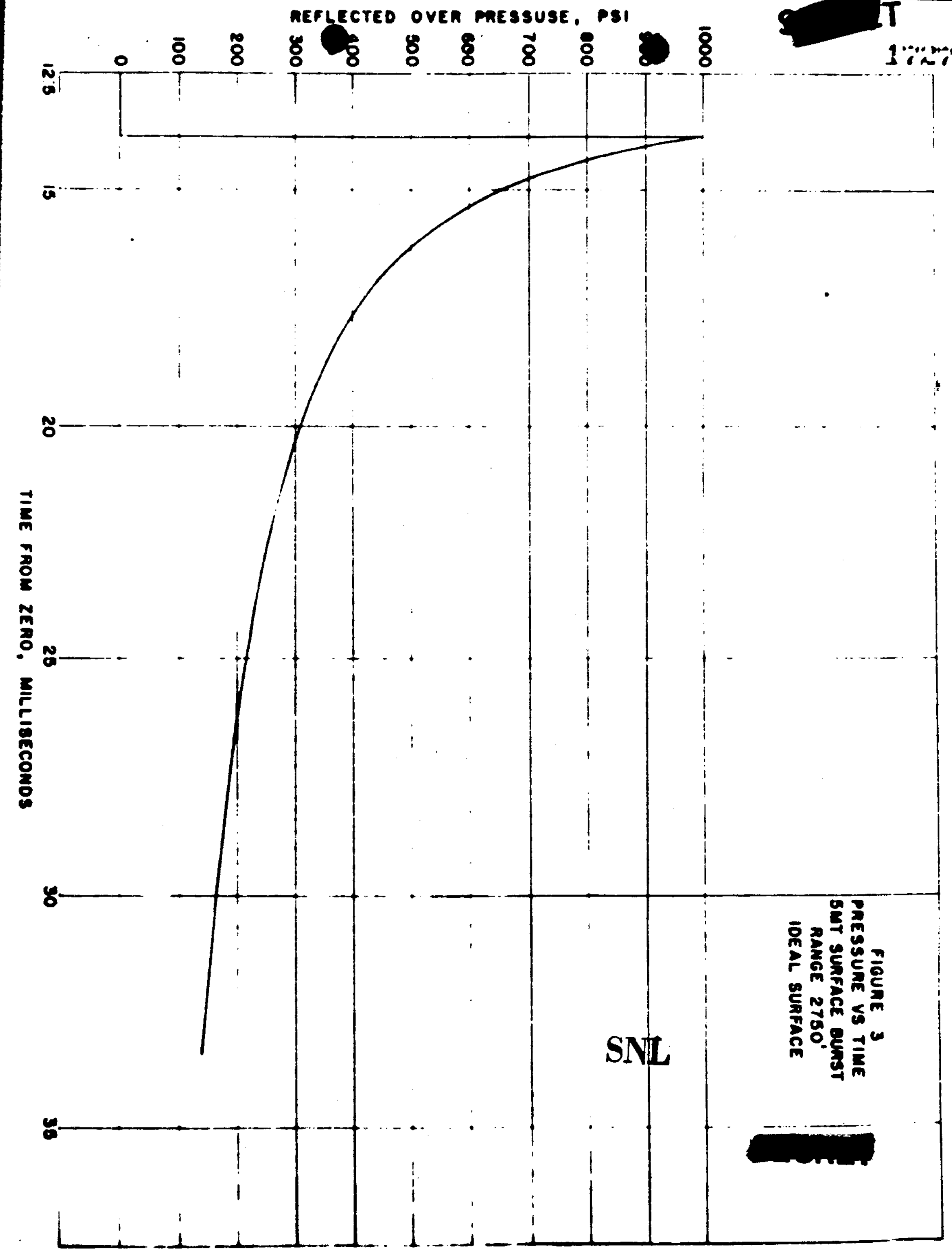

FIGURE 3
PRESSURE VS TIME
5MT SURFACE BURST
RANGE 2750'
IDEAL SURFACE

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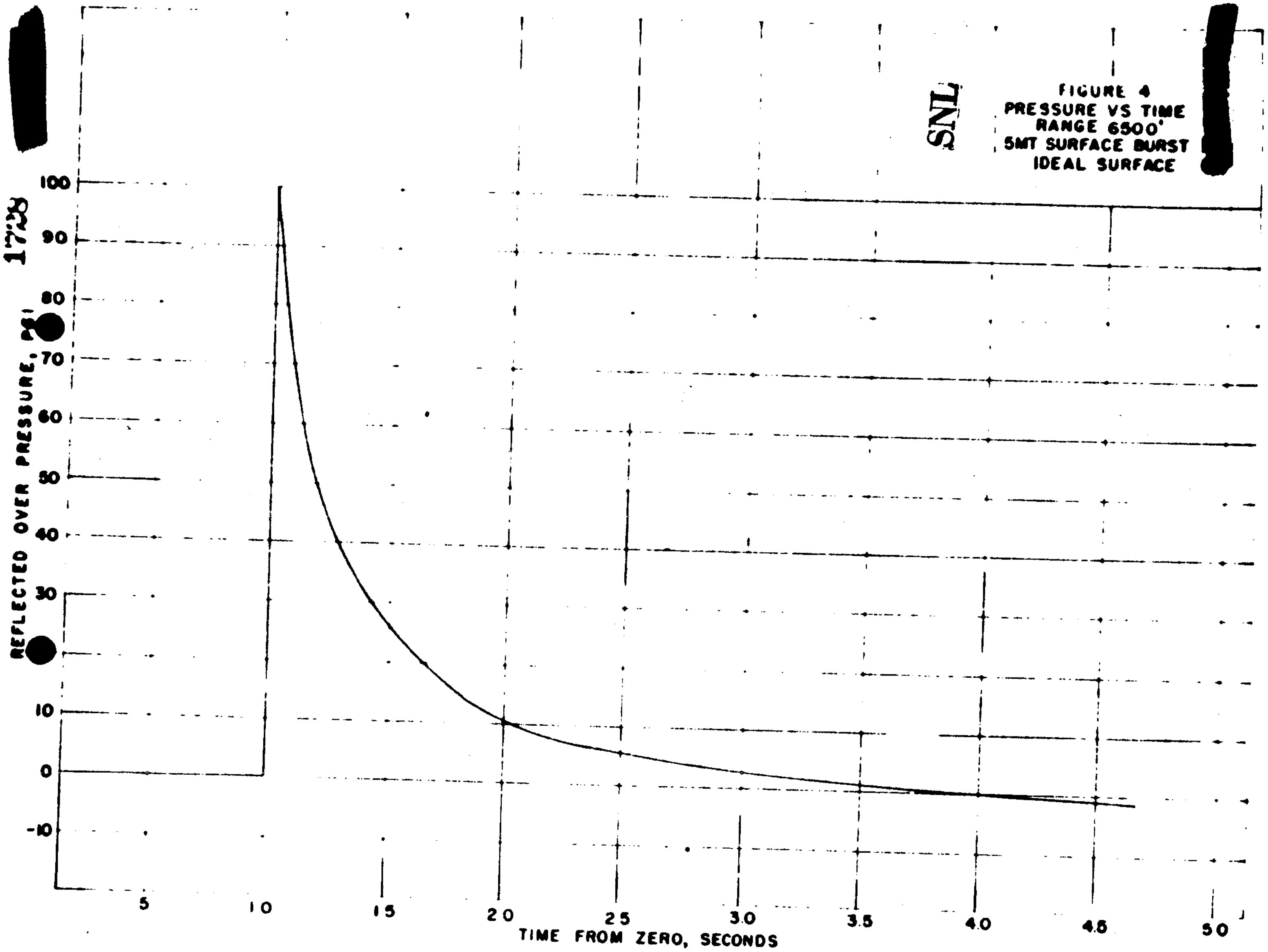

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FIGURE 4
PRESSURE VS TIME
RANGE 6500'
5MT SURFACE BURST
IDEAL SURFACE

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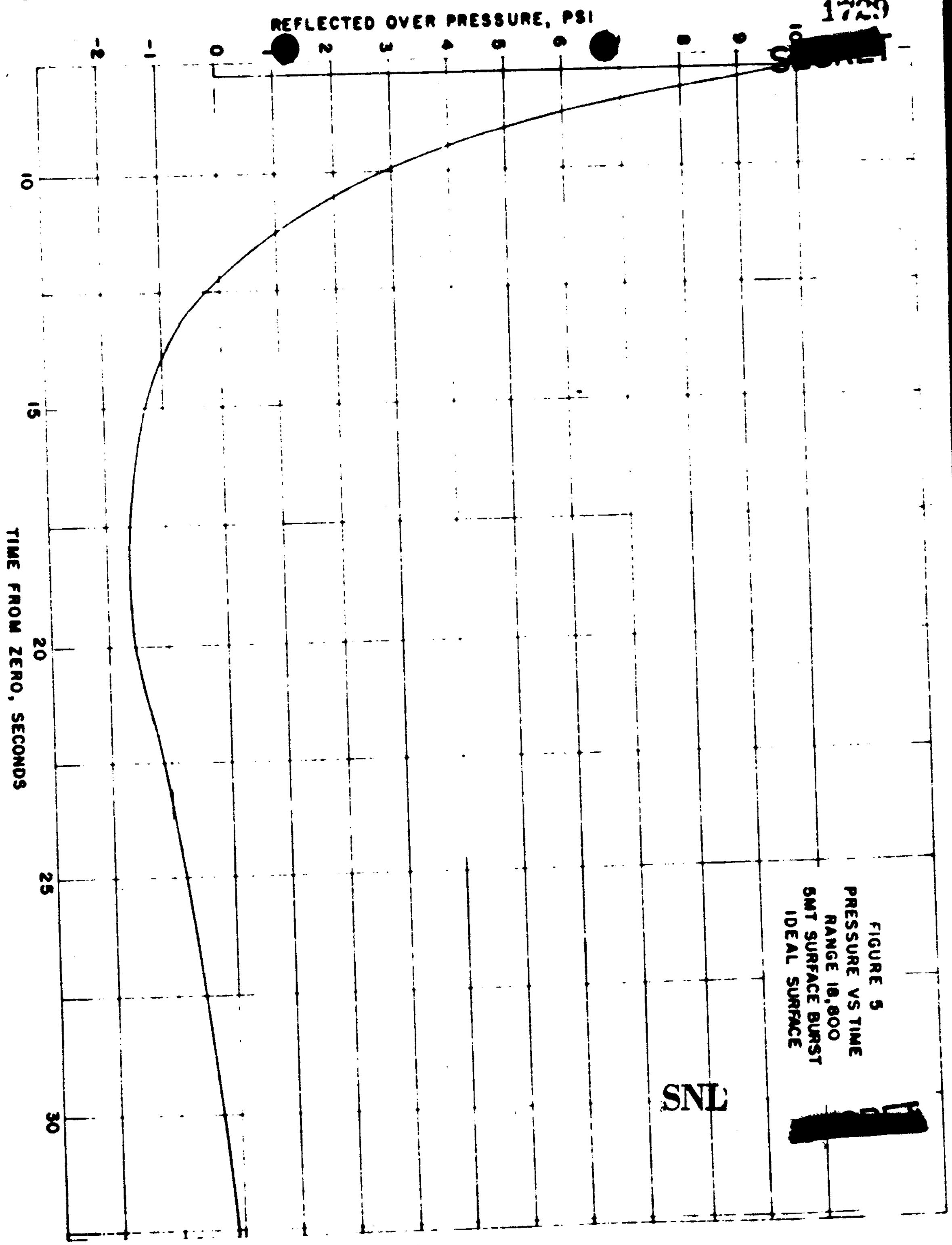

FIGURE 5
PRESSURE VS TIME
RANGE 18,800
5MT SURFACE BURST
IDEAL SURFACE

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TIME FROM ZERO, SECONDS

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TIME OF ARRIVAL, SECONDS

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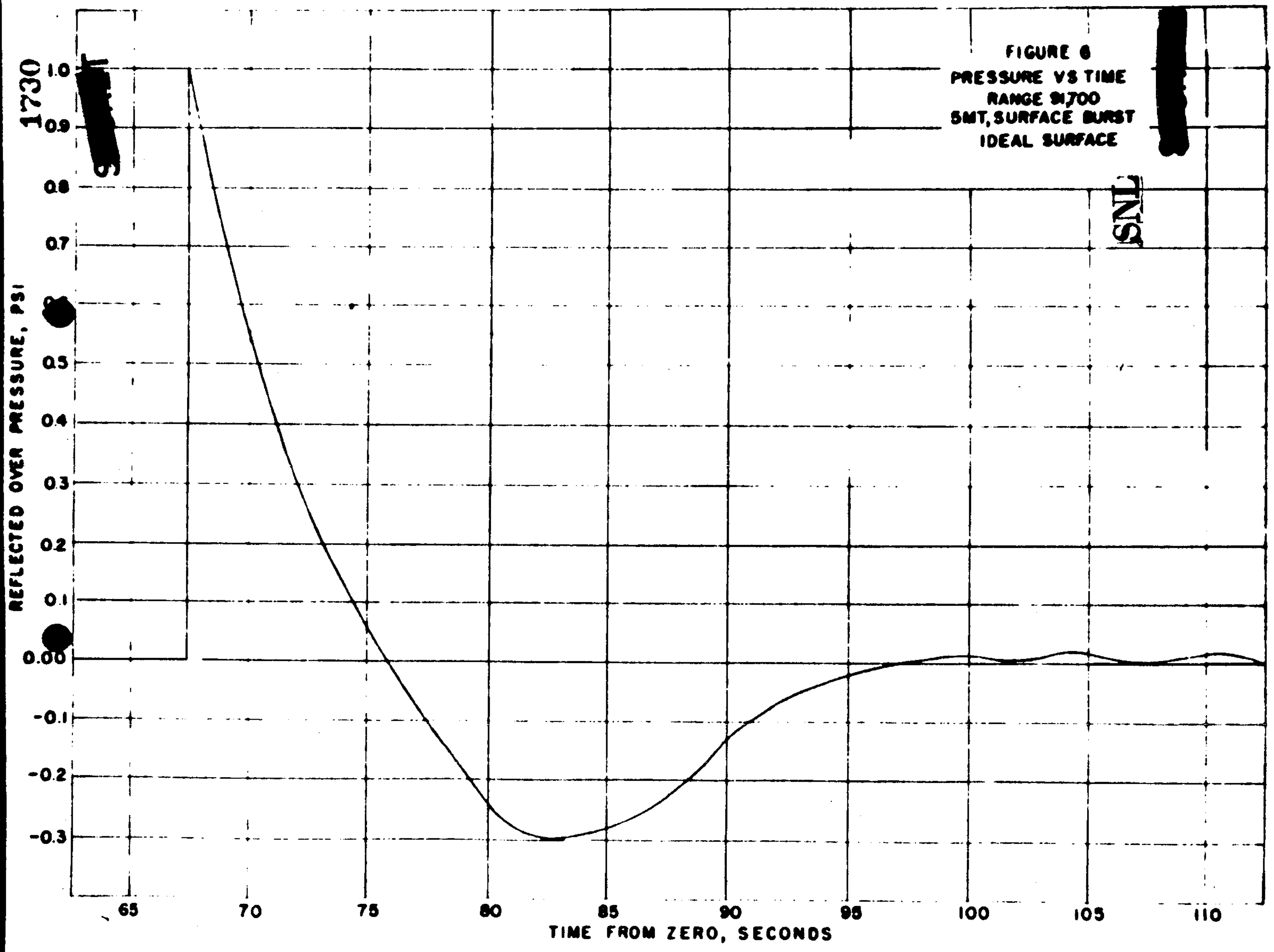

FIGURE 6
PRESSURE VS TIME
RANGE 91,700
5MT, SURFACE BURST
IDEAL SURFACE

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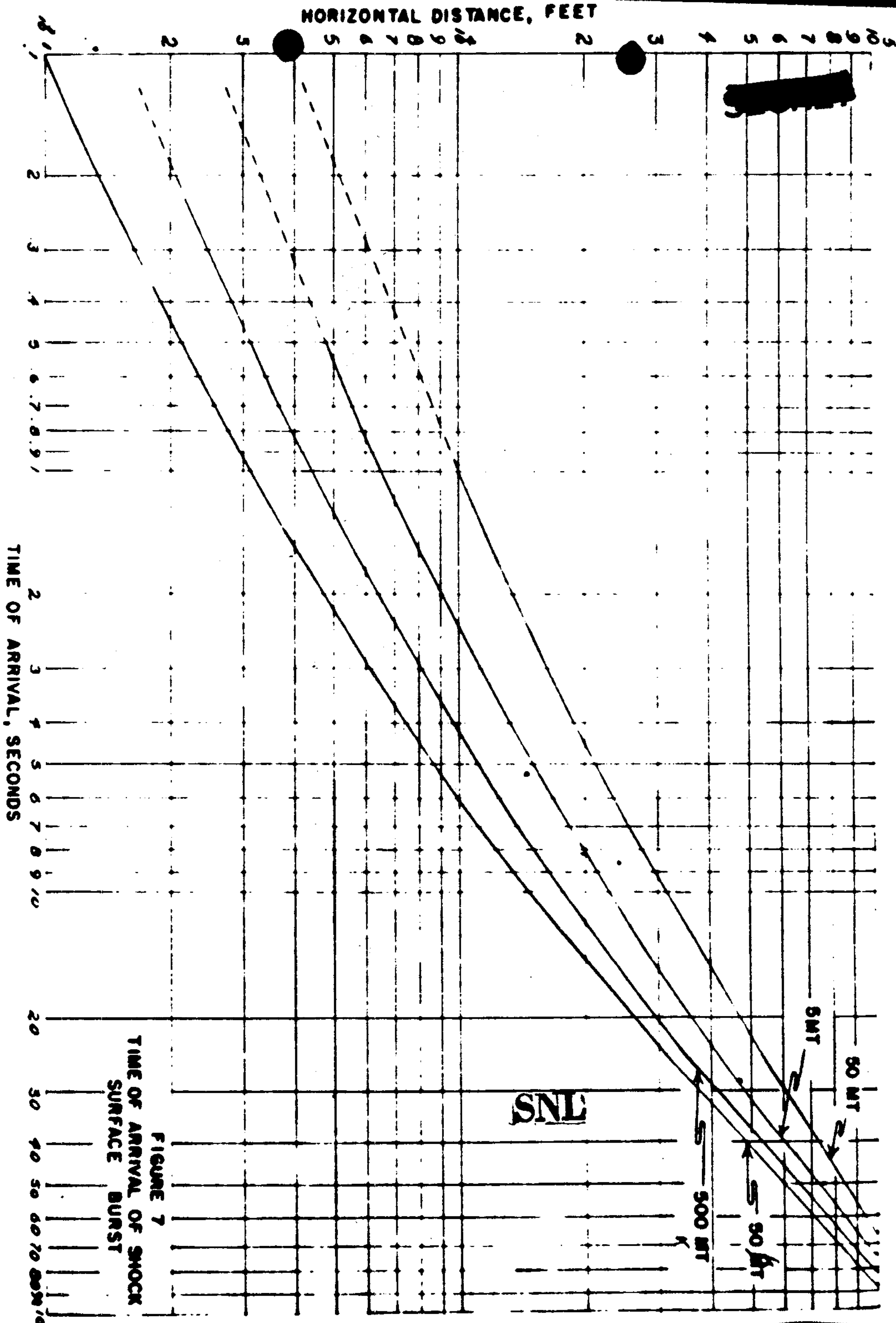

FIGURE 7
TIME OF ARRIVAL OF SHOCK
SURFACE BURST

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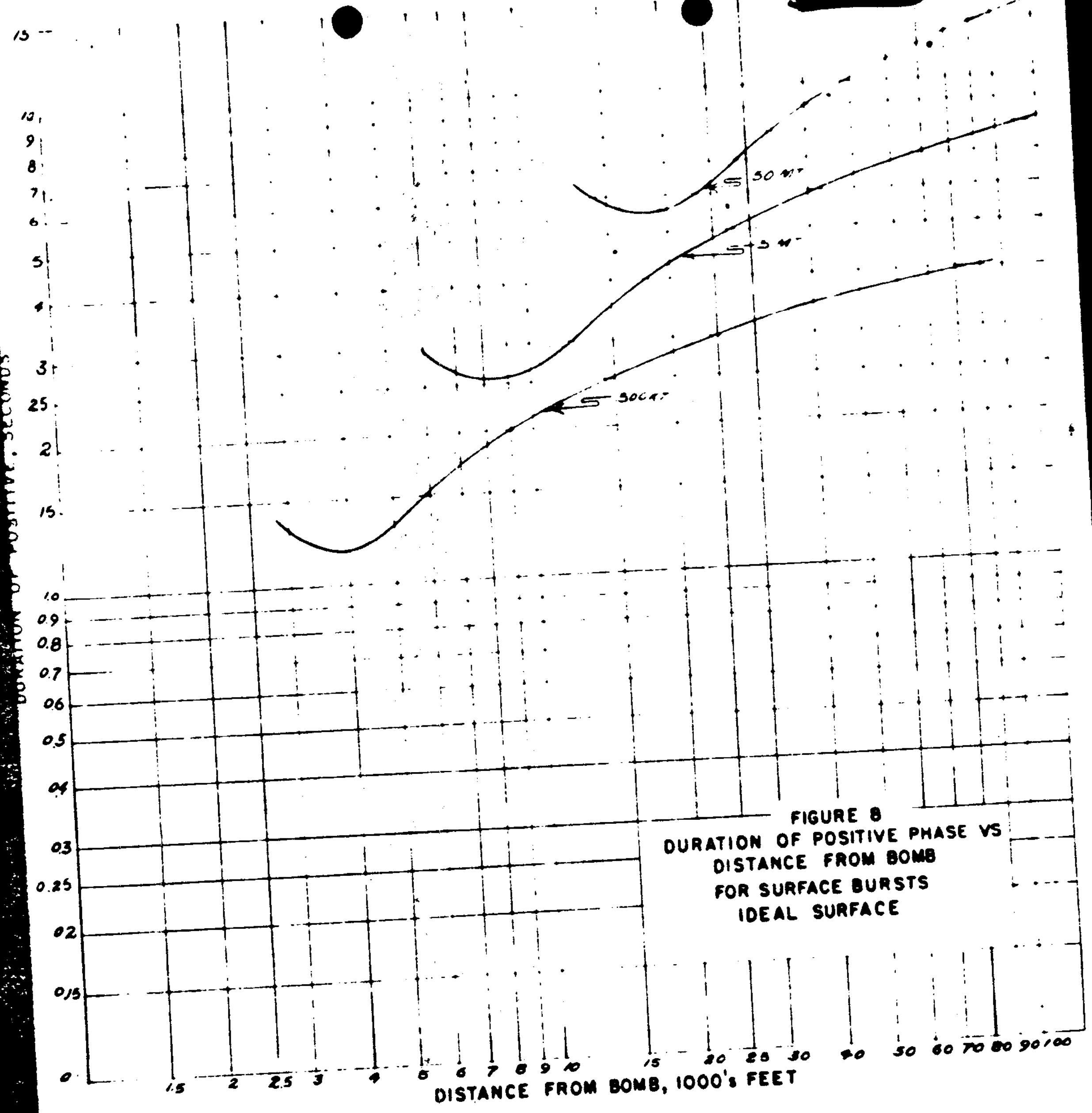

FIGURE 8
DURATION OF POSITIVE PHASE VS
DISTANCE FROM BOMB
FOR SURFACE BURSTS
IDEAL SURFACE

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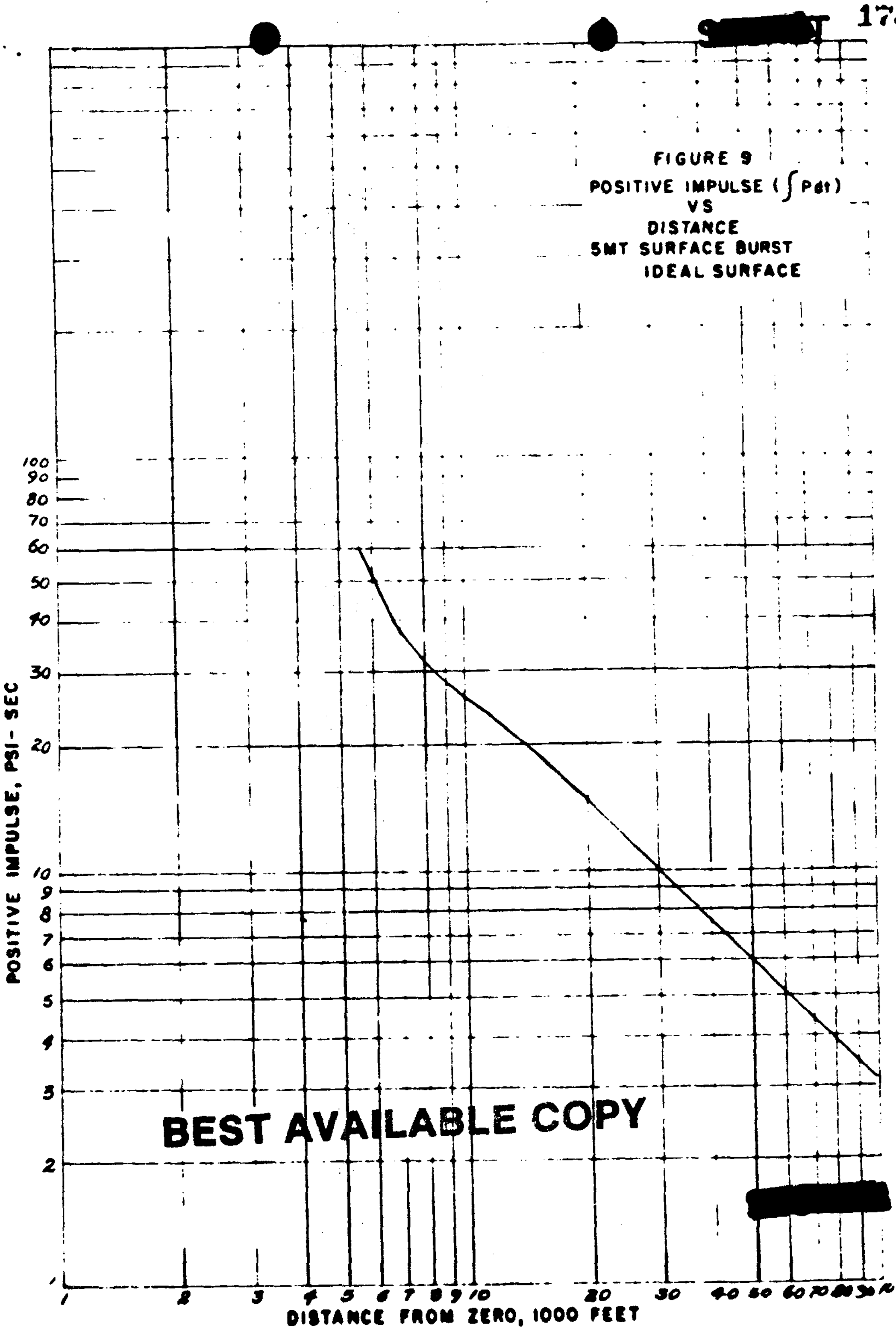

FIGURE 9
POSITIVE IMPULSE ($\int P dt$)
VS
DISTANCE
5MT SURFACE BURST
IDEAL SURFACE

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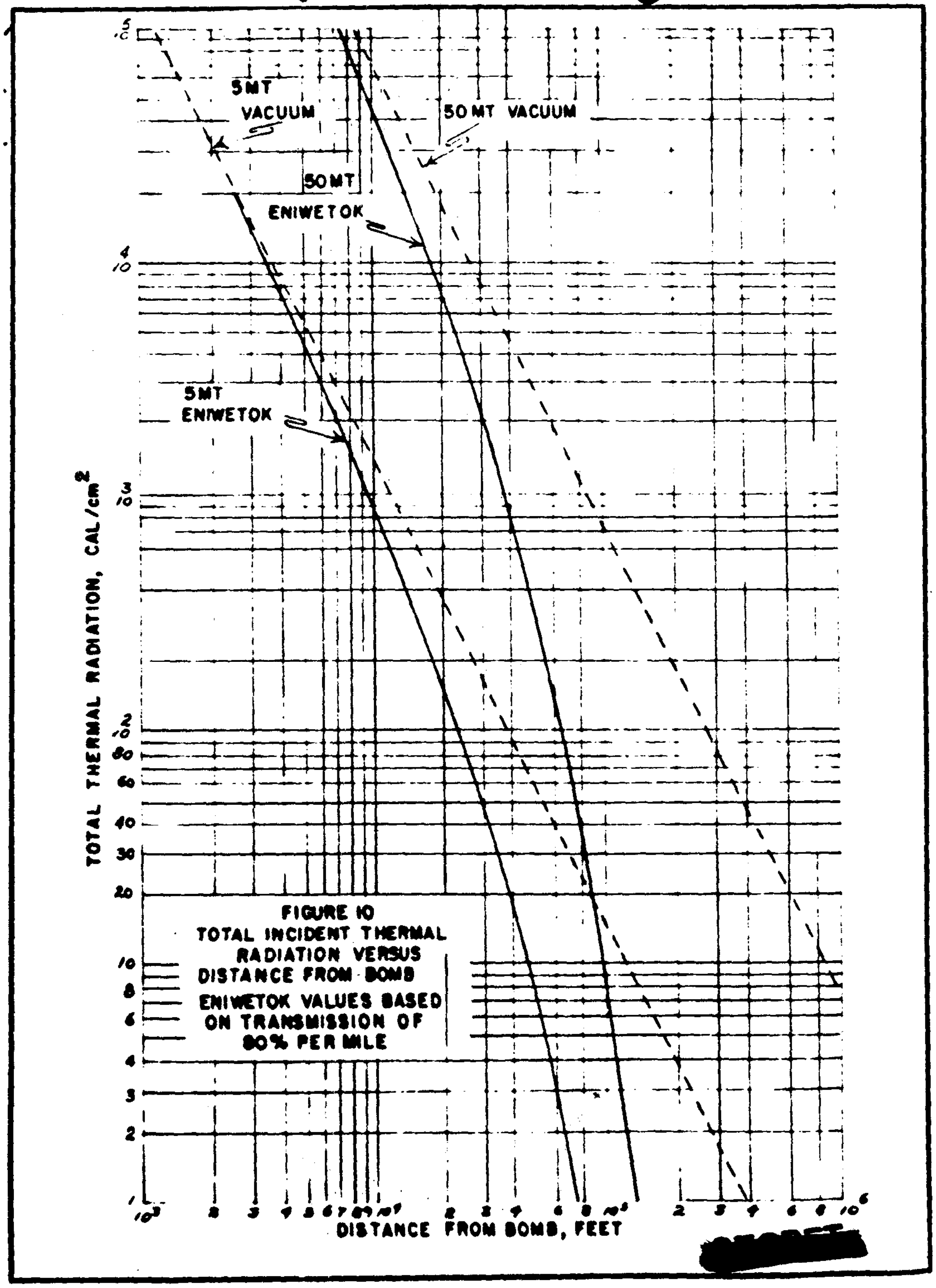

FIGURE 10
TOTAL INCIDENT THERMAL RADIATION VERSUS DISTANCE FROM BOMB
ENIWETOK VALUES BASED ON TRANSMISSION OF 80% PER MILE

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